

The University of Chicago

THERAPEUTIC VENOUS OCCLUSION

ITS EFFECT ON THE BLOOD FLOW IN THE EXTREMITY IN ACUTE ARTERIAL OBSTRUCTION

A PART OF A DISSERTATION SUBMITTED
TO THE FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SURGERY
1931

By
MELVILLE LAURENCE MONTGOMERY

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Vol. XXIV, No. 6, 1932

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CHICAGO

Artificial or therapeutic obstruction to the venous return from an extremity in which the arterial supply has been accidentally interrupted has been increasingly adopted as a means of lessening the usual high incidence of gangrene and muscular disturbances. This procedure has been developed during the present century, and its history was very clearly presented by Brooks¹ in his review of the subject in 1929. For the purposes of this paper it is sufficient to say that the clinical studies of Makins,² Sehart,³ and Propping⁴ and the experimental work of Drummond,⁵ Brooks and Martin,⁶ Holman and Edwards⁷ and others have been responsible for its widespread use in the treatment of patients with sudden occlusion of a healthy artery.

Such features of the clinical and experimental studies as have a bearing on my experimental work will be presented. The use of the procedure in chronic obliterative diseases of the arteries and its application in the treatment for arteriovenous aneurysms will not be discussed.

In summing up the experience of the British Army Medical Service in the district where he was working during 1915 and 1916, Makins presented figures on 172 cases of injury to the arteries of the extremities in which a comparison was made between ligation of the artery alone and ligation of both the artery and the vein. Efforts were made to rule out gangrene due to anaerobic infection. The table reproduces his figures. To them I have added the percentage columns.

From the Department of Surgery of the University of Chicago.

This work has been conducted under a grant from the Douglas Smith Foundation for Medical Research of the University of Chicago.

1. Brooks, Barney: *Surgical Applications of Therapeutic Venous Obstruction*, Arch. Surg. **19**:1 (July) 1929.

2. Makins, G. H.: *On Gunshot Injuries to the Blood Vessels*, New York, William Wood & Company, 1919.

3. Sehart, E.: *Med. Klin.* **12**:1338, 1916.

4. Propping, Karl: *München. med. Wchnschr.* **64**:598, 1917.

5. Drummond, H., quoted by Makins (footnote 2, p. 105).

6. Brooks, B., and Martin, K. A.: *Simultaneous Ligation of Vein and Artery*, J. A. M. A. **80**:1678 (June 9) 1923.

7. Holman, E., and Edwards, M. E.: *A New Principle in the Surgery of the Large Vessels*, J. A. M. A. **88**:909 (March 19) 1927.

Makins stated that the "table does not generally imply gangrene '*en masse*,' but in many cases a very limited amount confined to digits or patches of skin." His study was largely responsible for the acceptance of the principle of simultaneous ligation of the vein by the Interallied Congress of Surgeons in 1917.

In Germany, Sehrt reported that in the lower extremity, when the artery alone was ligated, gangrene occurred in 20.4 per cent of the cases, whereas it was seen in only 9 per cent when both the artery and the vein were tied. His figures for the occurrence of gangrene in the upper extremity were respectively 7.8 and 0 per cent. Propping reported two cases of ligation of the common carotid artery in which the internal jugular vein was also ligated, in one at the time of the ligation of the artery and in the other at a later date. In neither did symptoms of brain

A Comparison of the Results of Ligations of the Artery Alone with Those of Simultaneous Ligations of Artery and Vein

Artery	Artery Alone				Artery and Vein			
	Number of Cases	Good Result	Gangrene	Percentage of Gangrene*	Number of Cases	Good Result	Gangrene	Percentage of Gangrene*
Subclavian.....	4	3	1	25.0	1	1	..	0.0
Axillary.....	6	5	1	16.6	4	4	..	0.0
Brachial.....	13	10	3	23.0	1	1	..	0.0
Femoral.....	32	24	8	25.0	32	25	7	21.0
Popliteal.....	24	14	10	41.6	28	22	6	21.4
Tibial.....	4	4	..	0.0	1	1	..	0.0
Carotid.....	18	12	6	33.3	4	3	1	25.0
Total.....	101	72	29	28.0	71	57	14	19.7

* All the percentages were added to the table by me, except the total percentages, which appear in Makins' original table.

disturbance develop. This author made some studies on hydrostatics, using a rubber glove to represent the venous and capillary beds and varying the inflow and the resistance to outflow, which led him to believe that ligation of the vein restores the "circulatory balance" between inflow to and outflow from the extremity.

In the laboratory, Drummond found in the cat that when the main artery and vein supplying a loop of bowel were ligated, the incidence of gangrene was less than when the artery alone was occluded. Brooks and Martin, using rabbits, found that when the common iliac and external iliac arteries were ligated proximal and distal to the origin of the hypogastric artery, gangrene developed in 71.5 per cent of animals, whereas in a second series in which there was added to this procedure ligation of the common iliac vein, the incidence of gangrene was only 33.3 per cent. Holman and Edwards observed that when the common iliac artery and the inferior vena cava were ligated simultaneously in eighteen rabbits, only two cases of gangrene developed, and that none occurred in ten rabbits in which the common iliac and external

iliac arteries and the inferior vena cava were simultaneously obstructed. In this group of twenty-eight animals, gangrene was found in only 7.1 per cent.

In an effort to explain the beneficial effect of venous obstruction, studies were made to observe its influence on the flow of blood through the extremity.

Brooks and Martin, using anesthetized dogs, compared the temperatures of the tissues of both lower limbs (thigh and foot) with thermometers inserted into the substance of the limbs. They used room and rectal temperatures as control records. When the left iliac artery was ligated, the temperature of the left thigh and foot fell, whereas the other temperatures remained essentially unchanged. After the temperatures reached equilibrium, the left common iliac vein was ligated. A further fall in the temperature of the left thigh and foot occurred. These authors attributed the decrease in the temperatures of the left leg to a diminution in the flow of blood through the extremity. From this they concluded that ligation of the vein decreased the flow of blood through the extremity, and that the beneficial effects were due to some other cause. The explanation was to be found, they believed, in the elevation of the peripheral blood pressure which was observed on experimental animals by Van Kend,⁸ Hooker,⁹ Brooks and Martin and others. It was the opinion of the latter authors that the maintenance of a certain minimum peripheral blood pressure may be necessary to force blood through nonrigid, collapsed capillaries and perhaps to preserve the flow of nutrient material from the capillaries to the tissues; that when a major artery is ligated, the pressure falls below this critical level and is restored by the ligation of the concomitant vein. Brooks amplified this position in 1929.

On the other hand, Holman and Edwards stated the belief that ligation of the vein increased the flow of blood through the extremity, and that when the venous return was obstructed proximal to the point of arterial occlusion, the increase was greater than when the concomitant vein was ligated. Their opinion was based on experiments in which the superficial femoral artery in anesthetized and heparinized dogs was ligated and cannulated distal to the ligature. The rate of flow of blood from the distal stump through the cannula was measured in cubic centimeters per minute, and it was taken to represent the changes that were occurring in the blood flow through the leg. In one experiment with an animal weighing 10.4 Kg., the initial flow was 0.9 cc. When the superficial femoral vein was ligated, it rose to 2 cc. Ligation of the common iliac vein increased the flow to 10 cc. (an increase of over

8. Van Kend, quoted by Makins (footnote 2, p. 103).

9. Hooker, D. R., quoted by Halsted (footnote 15, p. 25).

1,000 per cent), and a further slight increase was noted on ligation of the inferior vena cava just proximal to its origin.

From these observation and their studies on the decreased incidence of gangrene in rabbits after proximal venous occlusion, Holman and Edwards concluded that obstruction of the venous return proximal to the point of arterial occlusion serves as a superior means of reducing the incidence of gangrene, largely because of the increase in blood flow which, they believed, occurred after its use.

Somewhat later Theis¹⁰ compared the flow of blood from the proximal end of the superficial femoral artery with that from the distal end both with and without ligation of the common iliac vein. Records were taken immediately after ligation and for varying periods afterward up to six weeks. Large dogs were used, and the operative procedure was carried out by means of aseptic technic. This author found that the normal flow of blood from the proximal end of the femoral artery averaged 240 cc. per minute. After ligation of the vein, the immediate per minute flow from the distal end of the artery was 48 cc. Ten minutes later it had risen to 51 cc. and one hour later to 54 cc. After the lapse of three weeks it was 96 cc. These results were compared with the effect of ligation on the superficial femoral artery alone on the opposite side of the same animal. Whereas the immediate flow from the proximal end of the femoral artery was the same¹¹ as that on the opposite side, the flow from the distal end was only 39 cc. After one hour the latter had increased to 54 cc. per minute, which was identical with that for the like period on the opposite side. Three weeks after ligation of the artery alone the flow had risen to 136 cc., in contrast with 96 cc. when both the artery and the vein were ligated.

From this and roentgen studies of the arterial circulation following injection of Hill's opaque mass, Theis concluded that the final collateral circulation is much better developed when the artery alone is ligated. Nevertheless he believed that "with sudden occlusion of a large artery . . . the immediate improvement in the collateral bed due to ligation of the concomitant vein is needed to maintain the vitality of the limb." This author also accepted increased discharge of blood from the distal end of a ligated femoral artery as evidence of an increase in the blood flow through the extremity.

Finally, in 1929 Brooks pointed out that instead of measuring the flow of blood through the limb, Holman and Edwards had determined only the amount of blood delivered by the collateral arterial circulation

10. Theis, F. V.: Ligation of Artery and Concomitant Vein in Operations on the Large Blood Vessels, *Arch. Surg.* **17**:244 (Aug.) 1928.

11. These figures do not actually represent the flow of blood through the superficial femoral artery at this point, because, under the conditions of the experiment, all arteriolar and capillary resistances have been removed.

to the distal arm of the femoral artery, and that when the vein was ligated the resulting rise in the venous blood pressure increased the resistance of the venous and capillary beds to the flow of blood and thereby sidetracked the blood coming through the collateral circulation from its normal channels into the open, low resistance femoral artery.

From a study of the work just reviewed it appeared that the divergence of opinions arose from the use of indirect methods for the determination of the blood flow. It seemed possible that the subject might be clarified by employing the recently devised, direct, continuous volume flow apparatus of Montgomery and Lipscomb.¹² To this end the experimental work reported in this paper was carried out. A preliminary report was made on part of this work in 1928.¹³ The final report has awaited perfection of the instrument.¹⁴

METHOD

Dogs weighing from 12 to 25 Kg. were anesthetized by the administration of sodium barbital, from 250 to 300 mg. per kilogram of body weight by stomach tube, or from 150 to 250 mg. per kilogram of body weight intravenously. In each animal one carotid artery, the right iliac and the common iliac veins, and the inferior vena cava at its origin were dissected out, care being taken to ligate all visible bleeding points. The animal was then allowed to remain undisturbed for from fifteen to thirty minutes to increase the assurance of coagulation of the very minute vessels. Heparin, 30 mg. per kilogram of body weight dissolved in 15 cc. of distilled water, was then injected intravenously as an anticoagulant. The systemic blood pressure was recorded from the carotid artery. The inlet and outlet arms of the volume flow apparatus were attached respectively to cannulas placed in the proximal and distal arms of the iliac artery. In a few cases T cannulas were placed in continuity in the superficial femoral artery and vein in order that the pressures in these vessels might be obtained before and after arterial and venous occlusion was done, and their side arms were connected with the usual form of mercury blood pressure manometer.

Ten experiments were performed. They were divided into two series. In the first, the systemic (carotid) arterial blood pressure, the superficial femoral arterial and venous blood pressures and the volume flow of blood through the iliac artery were recorded. In the second, the systemic (carotid) arterial blood pressure and the volume flow of blood through the iliac artery alone were obtained. The latter series was planned because it seemed probable from experience that the placing of T cannulas in the femoral vessels disturbed the mechanism of the vascular system considerably. This was especially noticeable in certain large animals in which the free iliac arterial blood flow was much below the expected. It was also found that the reactive hyperemia which followed temporary obstruction of the iliac artery while the instrument was being put into place was quite marked. To control this factor the blood was allowed to flow through the instrument for at least the length of time of the obstruction of the artery before the initial records of the arterial flow were recorded.

12. Montgomery, M. L., and Lipscomb, T. H.: *Am. J. Physiol.* **90**:454, 1929.

13. Montgomery, M. L.: *Effect of Therapeutic Venous Ligation on Blood Flow in Cases of Arterial Occlusion*, *Proc. Soc. Exper. Biol. & Med.* **27**:178, 1929.

14. Montgomery, M. L., and Lipscomb, T. H.: *A New Continuous Volume Flow Apparatus (Modified Ludwig-Stolnikow Stromuhr)*, to be published.

RESULTS

Series 1.—(Carotid arterial, superficial femoral arterial and superficial femoral venous blood pressures and volume flow of blood through the iliac artery were recorded). The following protocol is representative of this group:

The animal was a short-haired, male dog weighing 12.5 Kg. Sodium barbital, 3.75 Gm. or 0.3 Gm. per kilogram, was given by stomach tube. After free dissection of the superficial femoral artery and vein, the iliac artery and the iliac and common iliac veins, and the carotid artery on the right side, and the inferior vena cava at its origin, the animal was left alone for thirty minutes. Then 0.375 Gm. of heparin, dissolved in 15 cc. of distilled water, was injected intravenously, and T cannulas

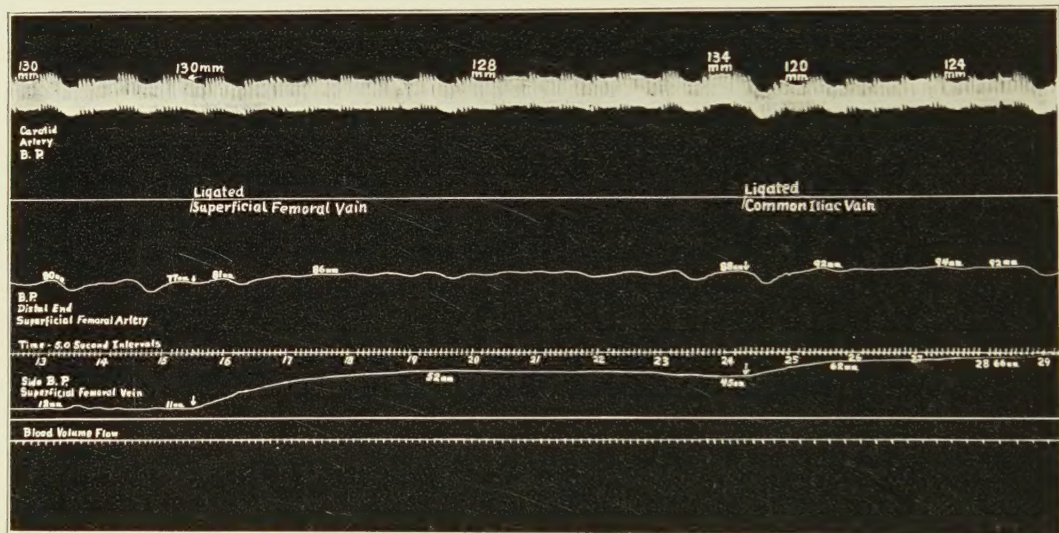


Chart 1.—Tracing showing the direct measurement of blood flow through the hind leg of a dog after ligation of the superficial femoral artery and subsequent "therapeutic" ligation of the superficial femoral vein and later of the common iliac vein. Ligation of the common iliac vein produced a marked decrease in the flow of blood through the leg.

were placed in the superficial femoral vessels and connected with mercury blood pressure manometers. The volume flow instrument was connected with the right iliac artery. The control flow through the iliac artery leveled off at about 40 cc. per minute. At this time the various blood pressures were as follows: carotid arterial, from 134 to 138 mm. of mercury; femoral arterial, from 118 to 126 mm. of mercury, and femoral venous, 16 mm. of mercury. Then the superficial femoral artery was ligated proximal to the T cannula and the flow of blood through the iliac artery fell abruptly to 29 cc. per minute, and later fluctuated between 31 and 36 cc. per minute. At the same time the femoral venous pressure leveled off at from 11 to 12 mm. of mercury and the femoral arterial at 80 mm. of mercury. After the flow had continued at this level for eight minutes, the superficial femoral vein was ligated. This caused the pressure in the superficial femoral artery and

vein to rise (chart 1). The former went from 77 mm. to 86 mm. of mercury and later reached 88 mm. of mercury. The latter rose from 11 mm. to 52 mm. of mercury and finally fell back to 45 mm. For a nine minute period the flow continued unchanged at a rate between 31 and 35 cc. per minute. When the common iliac vein was ligated, the rate fell sharply to 12.5 cc. per minute and finally leveled off at from 12 to 16 cc. per minute. At the same time the femoral arterial and venous pressures rose further, the former going from 83 to 92 mm. of mercury and the latter from 45 to 66 mm. of mercury. This rise occurred despite the fact that the systemic blood pressure, which had maintained a level of from 134 to 138 mm. of mercury, fell to from 120 to 124 mm. of mercury. Finally the inferior vena cava was ligated, and the flow fell sharply to 4.5 cc. per minute. This was accompanied by a fall in the systemic blood pressure to from 100 to 104 mm. of mercury, a slight fall in the superficial femoral arterial blood pressure to 88 mm. of mercury and a rise in the superficial femoral venous blood pressure to 72 mm. of mercury.

It should be stated that the high venous pressures developed in this experiment are not always seen. In the majority of cases, the rise is much less, but the comparative changes are otherwise similar in every way. In one such experiment, the venous pressure rose from a normal of 4 mm. to 20 mm. of mercury after ligation of the superficial femoral vein, and to 32 mm. after ligation of the common iliac vein.

Series 2.—(Carotid arterial blood pressure and volume flow of blood through the iliac artery were recorded.) The following protocol is representative of this group:

A long-haired, male dog, weighing 22.8 Kg., was used. Sodium barbital anesthesia was obtained with an initial dose of 2.6 Gm. injected intravenously, followed thirty minutes later by 1 Gm. intravenously. The animal was even then under light anesthesia as reflected in the respiratory fluctuations of blood pressure and blood flow, during deep respirations (fig. 2). These fluctuations were later controlled by small amounts of ether. The systemic blood pressure was taken from the left carotid artery. The right superficial femoral artery and vein were exposed only enough to permit ligation. The iliac artery was exposed freely as were the iliac and common iliac veins. The inferior epigastric artery and vein were ligated, to eliminate the drain of blood away from the extremity, and the animal was then left for fifteen minutes to aid coagulation of the small, invisible bleeding points. Then 0.68 Gm. of heparin, dissolved in 15 cc. of distilled water, was injected intravenously, and the volume flow instrument was connected with the right iliac artery. Ten minutes was required to make this connection, and in order to correct for reactive hyperemia the blood was allowed to flow through the instrument for a like period before the control record was taken.

Sharp fluctuations in the systemic blood pressure accompanied the deep respiratory movements and were associated with transient but marked changes in the rate of blood flow. As will be seen, however, the respiratory effects did not change the general trend. The control period flow of blood ranged between 123 and 130 cc. per minute for a ten minute period. Then the superficial femoral artery was ligated, and the flow fell rather quickly to 72 cc. per minute, after which it ranged between 70 and 80 cc. per minute for ten minutes. During this time the carotid arterial blood pressure fluctuated between 140 and 144 mm. of mercury. Ligation of the superficial femoral vein was now carried out and the rate of flow recorded

for sixteen minutes. At first the rate was unchanged. Then there was a moderate fall to range between 65 and 68 cc. per minute. The carotid arterial blood pressure was unchanged. At the end of this time the ligature about the superficial femoral vein was released. There was no immediate change in the rate of blood flow or in the systemic blood pressure. After eight minutes, however, the rate had fallen to between 58 and 60 cc. per minute. This was accompanied by a fall in carotid arterial blood pressure to 136 mm. of mercury.

With the femoral vein open, the iliac vein was ligated. This caused a prompt fall in the carotid arterial blood pressure from 136 to 130 mm. of mercury, and a sharp decrease in the volume flow of blood to 40 cc. per minute. This rate remained fairly constant for seventeen minutes. Then ligation of the common iliac vein reduced the blood flow to between 30 and 35 cc. per minute and the blood pressure to between 120 and 124 mm. of mercury.

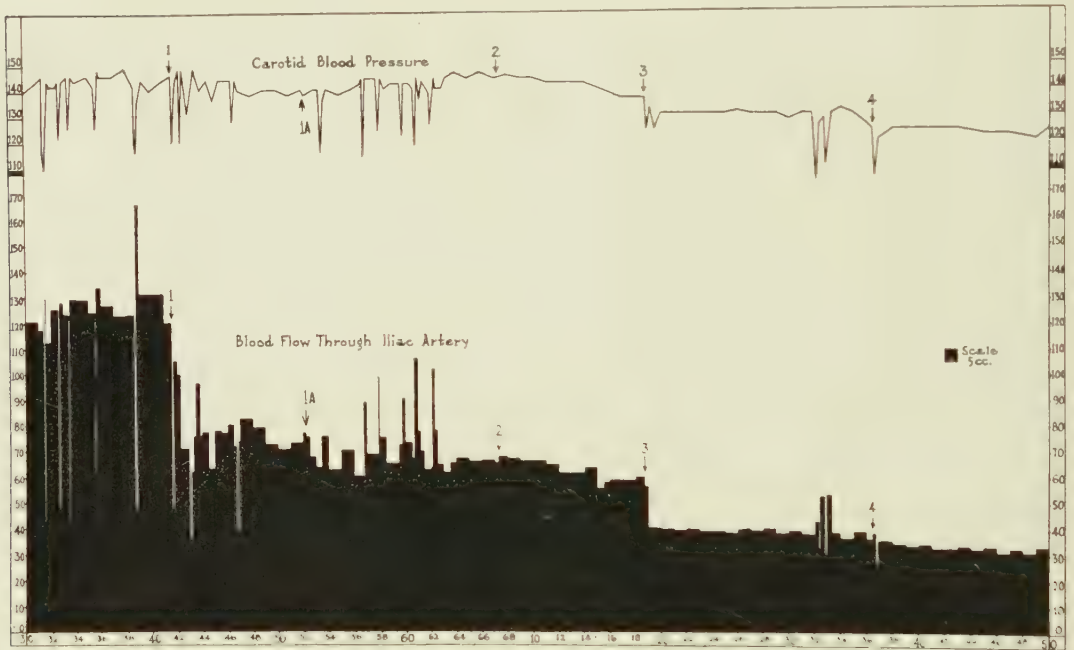


Chart 2.—Tracing showing the direct measurement of blood flow through the hind leg of a dog after ligation of the superficial femoral artery and subsequent "therapeutic" ligation of the superficial femoral vein, the iliac vein and finally the common iliac vein. The ligation of the latter two veins caused a decided reduction in the blood flow through the leg. 1 shows superficial femoral artery ligated; 1A, superficial femoral vein ligated; 2, ligature about superficial femoral vein released; 3, iliac vein ligated; 4, common iliac vein ligated.

SUMMARY

A fall in systemic blood pressure after ligation of the common iliac vein was observed in six of the ten experiments. The amount was quite variable. In four cases it ranged between 6 and 8 mm. of mercury. In two instances, with marked circulatory changes, it was much greater. Of the four other experiments there was observed a slight

transient fall in one, which rapidly returned to "normal"; in another there was no change; in the two remaining, the results were unsatisfactory.

The relationship between the fall in systemic blood pressure and the degree of decrease in the blood flow in our experiments is only a matter for speculation at present. Should a serious fall in blood pressure occur, it would, of course, affect the blood flow, but whether, with an otherwise adequate blood pressure, lesser changes of from 6 to 8 mm. of mercury exert an appreciable influence cannot be stated from the data at hand.

The superficial femoral vein was ligated in four experiments, and in each instance there was no increase in the flow of blood. The rate remained unchanged or decreased slightly during the eight to fifteen minutes of observation. In nine of the ten experiments, the common iliac vein was ligated, and in each instance there was an immediate, definite and at times pronounced fall in the per minute flow of blood. In the two experiments in which the inferior vena cava was ligated after ligation of the common iliac vein, there was a marked further decrease in the flow of blood which was associated with a rather sharp fall in the systemic blood pressure.

In each instance in which the vein was ligated, whether it was the superficial femoral, the iliac, the common iliac or the inferior vena cava, a rise occurred in the peripheral venous blood pressure. A similar rise was observed in the peripheral arterial pressure, except after ligation of the inferior vena cava, when, in one case, a slight fall was seen (see protocol, series 1). This fall seems to have occurred because the systemic pressure was closely approaching the level of the peripheral arterial pressure. In general, the peripheral blood pressures became higher with the more cephalad placing of the ligature.

When the common iliac vein was ligated permanently, dissection of the vascular bed after completion of the experiment showed the veins to be markedly distended with blood, in contrast with the collapsed, empty state of the veins of the opposite extremity.

COMMENT

It is evident from the results of these experiments that in the presence of acute obstruction of the superficial femoral artery in dogs, ligation of the superficial femoral vein, the iliac vein, the common iliac vein or the inferior vena cava does not increase the flow of blood to the extremity through the iliac artery. Indeed when, in these studies, any of the veins named were ligated, except only the superficial femoral, there occurred a definite decrease in the flow of blood so that as the position of the ligature became more cephalad the decrease became more pronounced. When the concomitant superficial femoral vein was ligated, the flow was either unchanged or decreased moderately. Whether ligation of the concomitant vein in other locations (as ligation of the iliac

artery and vein) has a similar or a different effect on the flow of blood to the part must await further experiments on a different species of animal, since the dog has no common iliac artery. The experiments of Brooks and Martin in which the common iliac vein was ligated after tying the iliac artery are, in fact, an application of the principle of proximal venous occlusion, and the decrease in blood flow which they postulated from the fall in temperature must be considered in that light.

The belief that ligation of the vein increases the flow of blood through the extremity must, therefore, be discarded, and the cause of such benefits as accrue from its use must be sought for elsewhere. The opinion of Brooks and Martin that ligation of the vein reestablishes the reduced peripheral blood pressure to a level above the minimum necessary to maintain a sufficient distribution of blood throughout the various capillary beds and to preserve the head of pressure required for the passage of nutrient elements from those capillaries into the surrounding tissues seems logical. Such benefits as occur are probably due to such a change.

On the other hand, as pointed out by these authors, the mere raising of the blood pressure is not sufficient. There must be a circulation of blood adequate for the basal conditions existing, and if ligation of the vein should produce a marked venous stasis, this stasis might be more menacing to final recovery than the reduction of pressure, especially if the latter was soon increased by the action of the collateral circulation. From such a stasis so-called ischemic paralysis might develop, with all of its attendant evils.

In addition, obstruction of the venous return may disturb the development of the collateral circulation as was proposed by Halsted.¹⁵ This author writes:

Since ligation of the vein raises the blood pressure in the ischemic area, is it not possible that the response of the arterial side for anastomotic development may be delayed or lessened for a period and to a degree conformable to the time and amount that the obstruction of the vein contributes to the maintenance of the circulation of the extremity? If this is so, might not the ligation of the like-named vein be postponed, when this can be done without danger, in order not to relieve the arterial side of its responsibility? Then if after a time there should be evidence of disability from ischemia, such as claudication on exercise, the surgeon would have the ideal opportunity to demonstrate the value of the venous ligation.

Halsted's conception is supported by the experiments of Theis, who found, on comparing ligation of the artery alone with ligation of the artery and vein (superficial femoral artery, common iliac vein), that, after the former procedure, the discharge of blood from the peripheral end of the ligated and divided femoral artery was at first smaller than, within an hour equal to, and three weeks later greater than after the latter procedure. This difference seems explainable only if it is assumed

15. Halsted, W. S.: Ligations of the Left Subclavian Artery in Its First Portion, *Johns Hopkins Hosp. Rep.* **21**:1, 1921.

that there has been a better development of the collateral circulation to the femoral artery following ligation of the artery alone. Here again the principle of proximal venous occlusion has been used without clearly recognizing its import, as the author refers in his title to "Ligation of . . . Concomitant Vein . . . " Whether ligation of the concomitant vein will show similar results remains undetermined. This work should be repeated and extended, as it has a fundamental bearing on the problem.

Recently the procedure has been brought into question further as the result of some experimental work on rabbits carried out in this laboratory by Wilson.¹⁶ In two series of experiments in each of which thirty animals were used, this worker ligated the iliac and common iliac arteries alone in one and ligated these arteries and the common iliac vein in the other. The incidence of gangrene was the same in both, 43 per cent. In addition, the functional results seemed to be somewhat more favorable after ligation of the artery alone, both as to the speed and as to the completeness of recovery.

Finally, a more careful analysis of the clinical reports leads one to feel that the procedure, as a method for general use, may have been received with too much favor. Makins' combined figures show, to be sure, a differential in favor of simultaneous ligation of the vein in the reduction of gangrene of 8.3 per cent (28 to 17.7 per cent). When the data are broken down into their component parts, however, it is found that there are great variations for the different parts of the body. The figures for the subclavian, axillary, brachial and carotid arteries seem overwhelmingly in favor of ligation of the vein. Nevertheless, the cases in which this procedure was carried out in each category are in reality too few to be of value in making significant deductions. On the other hand, for ligation of the femoral artery there was no essential difference between the two methods. The really promising results were found in the cases requiring ligation of the popliteal artery. Here the differential in favor of ligation of the vein was 20.2 per cent (41.6 to 21.4 per cent).

Sehrt's data, although favorable, are incapable of analysis and, for that reason, must be held in abeyance. Propping's two cases support the case for ligation of the vein when the carotid artery must be occluded.

Unfortunately Makins was unable to gather any important data on the final functional results in his cases. This is, after all, the real test of the method, and before its proper place in the surgery of the vascular system can be estimated, every effort must be made to study carefully and for a prolonged period of time each case that requires ligation of the healthy artery of an extremity, to the end that a larger clinical

16. Wilson, W. C., to be published.

material may be available for analysis. To this must be added a larger mass of experimental data analyzing carefully the effects of the various procedures on the vascular systems in the different parts of the body.

For the present, if the concomitant vein must be ligated, it appears that the ultimate prognosis will not be unfavorable in the majority of cases. If the popliteal artery has to be ligated, and the patient cannot be kept under careful observation, ligation of the concomitant vein should be practiced. If, however, the vein is intact and the patient is under careful observation, it may be well, as suggested by Halsted¹⁵ and Brooks,¹ to wait on the development of impending gangrene or symptoms of local circulatory insufficiency before resorting to ligation of the vein in any region. Then, if ligation seems desirable, it should be limited to the concomitant vein.

CONCLUSIONS

1. It has been shown in heparinized animals under sodium barbital anesthesia that after ligation of the superficial femoral artery:

(a) Ligation of the concomitant, superficial femoral vein causes no increase in the per minute volume flow of blood through the iliac artery, but causes either no change or a slight decrease, during the period of examination (from eight to fifteen minutes).

(b) Obstruction of the proximal venous return by ligation of the iliac vein, the common iliac vein or the inferior vena cava causes a pronounced decrease in the per minute volume flow of blood, the decrease being more marked the more cephalad the ligature is placed.

(c) In confirmation of the findings of Van Kend, Brooks and Martin and others, obstruction of the venous return increases the peripheral arterial and venous blood pressure and, in general, the increase is more marked the higher (more cephalad) the ligature is placed.

2. Because of the marked decrease in the flow of blood which follows obstruction of the venous return proximal to the point of arterial occlusion, and because of the possible danger of producing a serious venous stasis thereafter, it would appear that the use of this principle in the treatment of patients requiring ligation of the main artery of an extremity should be avoided.

3. The employment of ligation of the concomitant vein for occlusions of the injured, but otherwise healthy, popliteal artery is strongly supported by the clinical data. Its use in other locations is still a subject for debate and should await further experimental and clinical studies.

4. For the present, in the treatment of acute obstructions of the main arterial supply of an extremity, except the popliteal artery, in the absence of injury to the concomitant vein it seems wise to await the appearance of impending gangrene before resorting to ligation of the vein.

